US007496178B2

(12) **United States Patent**
Turner

(10) **Patent No.: US 7,496,178 B2**
(45) **Date of Patent: *Feb. 24, 2009**

(54) **PORTABLE X-RAY DEVICE**

(75) Inventor: **D. Clark Turner**, Payson, UT (US)

(73) Assignee: **Aribex, Inc.**, Orem, UT (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 395 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/529,805**

(22) PCT Filed: **Feb. 18, 2005**

(86) PCT No.: **PCT/US2005/005712**

§ 371 (c)(1),
(2), (4) Date: **Aug. 1, 2005**

(87) PCT Pub. No.: **WO2005/081956**

PCT Pub. Date: **Sep. 9, 2005**

(65) **Prior Publication Data**

US 2007/0269010 A1 Nov. 22, 2007

Related U.S. Application Data

(60) Provisional application No. 60/546,575, filed on Feb. 20, 2004.

(51) **Int. Cl.**
H05G 1/10 (2006.01)

(52) **U.S. Cl.** **378/101**; 378/102

(58) **Field of Classification Search** 378/98, 378/98.2, 98.8, 101–104, 109–112, 119, 378/191

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,728,457 A 4/1973 Lundin

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0247758 12/1987

(Continued)

OTHER PUBLICATIONS

Fiorini, C.; Longoni, A.; Milazzo, M.; Zaraga, F, *In-situ, non-destructive identification of chemical elements by means of portable EDXRF spectrometer*. Nuclear Science Symposium, 1998. Conference Record. 1998 IEEE, vol. 1, Iss., 1998, pp. 375-380, vol. 1 (Abstract).

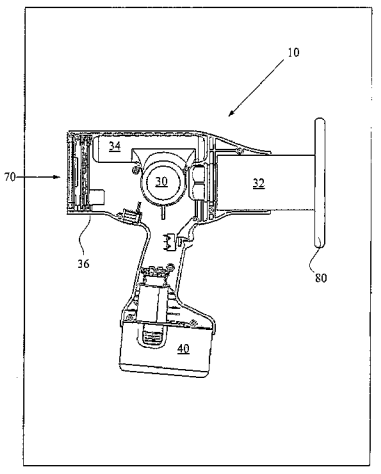
(Continued)

Primary Examiner—Irakli Kiknadze
(74) *Attorney, Agent, or Firm*—Kenneth E. Horton; Kirton and McConkie

(57) **ABSTRACT**

Portable x-ray devices and methods for using such devices are described. The devices have an x-ray tube powered by an integrated power system. The x-ray tube is shielded with a low-density insulating material containing a high-Z substance. The devices can also have an integrated display component. With these components, the size and weight of the x-ray devices can be reduced, and the portability of the devices enhanced. Thus, the portable x-ray devices are especially useful for applications where portability is an important feature such as in field work, remote operations, and mobile operations such nursing homes, home healthcare, teaching classrooms. This portability feature can be particularly useful in multi-suite medical and dental offices where a single x-ray device can be used in multiple offices instead of single using an x-ray device in each office.

24 Claims, 9 Drawing Sheets



U.S. PATENT DOCUMENTS

3,828,194	A		8/1974	Grasser
3,925,672	A		12/1975	Soder et al.
4,039,811	A		8/1977	Ennslin et al.
4,191,889	A		3/1980	Cowell
4,221,969	A		9/1980	Schmidt
4,311,913	A		1/1982	Resnick et al.
4,490,834	A		12/1984	Sudani
4,646,338	A		2/1987	Skillicorn
4,694,480	A		9/1987	Skillicorn
4,768,216	A		8/1988	Harvey et al.
4,775,992	A		10/1988	Resnick et al.
4,797,907	A		1/1989	Anderton
4,809,311	A		2/1989	Arai et al.
4,811,375	A		3/1989	Klostermann
4,856,036	A		8/1989	Malcolm et al.
4,930,146	A		5/1990	Flakas et al.
4,979,198	A		12/1990	Malcolm et al.
5,077,771	A		12/1991	Skillicorn
5,111,493	A		5/1992	Siedband
5,153,900	A		10/1992	Nomikos et al.
5,379,335	A		1/1995	Griesmer et al.
5,442,677	A	*	8/1995	Golden et al. 378/102
5,631,943	A		5/1997	Miles
5,708,694	A		1/1998	Beyerlein et al.
6,038,287	A		3/2000	Miles
6,205,200	B1		3/2001	Boyer et al.
6,282,260	B1	*	8/2001	Grodzins 378/87
6,327,338	B1		12/2001	Golovanivsky
6,459,767	B1		10/2002	Boyer
6,661,876	B2		12/2003	Turner et al.
6,822,250	B2	*	11/2004	Korenev 250/492.3
2003/0002627	A1		1/2003	Espinosa et al.
2003/0048877	A1		3/2003	Price et al.
2003/0142788	A1		7/2003	Cho et al.
2005/0018817	A1		1/2005	Oettinger et al.
2005/0053199	A1		3/2005	Miles
2005/0213709	A1		9/2005	Dinsmore et al.

FOREIGN PATENT DOCUMENTS

EP	0488991	6/1992
EP	0524064	1/1993
EP	0784965	7/1997
JP	59-073897	4/1984
JP	62-246300	10/1987
JP	62-283600	12/1987
JP	03-225797	10/1991
WO	WO 92-04727	3/1992
WO	WO 95/20241	7/1995
WO	WO 96-05600	2/1996
WO	WO 2004047504	6/2004
WO	WO 2005008195	1/2005

OTHER PUBLICATIONS

Mesyats, G.A.; Shpak, V.G.; Yalandin, M.I.; Shunailov, S.A. *RADAN-EXPERT portable high-current accelerator*, Pulsed Power Conference, 1995. Digest of Technical Papers. Tenth IEEE International, vol. 1, Iss., Jul. 3-6, 1995, pp. 539-543 vol. 1 (Abstract).

Fiorini, C.; Longoni, A. *In-situ, non-destructive identification of chemical elements by means of portable EDXRF spectrometer*, Nuclear Science, IEEE Transactions on, vol. 46, Iss. 6, Dec. 1999 pp. 2011-2016 (Abstract).

Bertolucci, E.; Boerkamp, T.; Maiorino, M.; Mettivier, G.; Montesi, M.C.; Russo, P. *Portable system for imaging of/spl alpha/, and X-ray sources with silicon pixel detectors and Medipix1 readout*, Nuclear Science, IEEE Transactions on, vol. 49, Iss. 4, Aug. 2002 pp. 1845-1850 (Abstract).

Mesyats, G.A.; Korovin, S.D.; Rostov, V.V.; Shpak, V.G.; Yalandin, M.I., *The RADAN series of compact pulsed power Generators and their applications*, Proceedings of the IEEE, vol. 92, Iss. 7, Jul. 2004 pp. 1166-1179 (Abstract).

Kastis, G.A.; Furenlid, L.R.; Wilson, D.W.; Peterson, T.E.; Barber, H.B.; Barrett, H.H., *Compact CT/SPECT small-animal imaging system*, Nuclear Science, IEEE Transactions on, vol. 51, Iss. 1, Feb. 2004 pp. 63-67 (Abstract).

Shrivastave, P.; O'Connell, S.; Whitley, A., *Handheld x-ray fluorescence: practical application as a screening tool to detect the presence of environmentally-sensitive substances in electronic equipment*, Electronics and the Environment, 2005. Proceedings of the 2005 IEEE International Symposium on, vol., Iss., May 16-19, 2005 pp. 157-162 (Abstract).

Idrissi, M.M.; Dudemaine, M.; Viladrosa, R.; Robert, E.; Cachoncinlle, C.; Pouvesle, J.M., *Experimental study and development of a single focus burst X-ray flash*, Pulsed Power Conference, 2003. Digest of Technical Papers. PPC-2003. 14th IEEE International, vol. 2, Iss., Jun. 15-18, 2003 pp. 752-755 vol. 2 (Abstract).

Maur, F., *X-ray inspection for electronic packaging latest developments*, Electronic Packaging Technology Proceedings, 2003. ICEPT 2003. Fifth International Conference on, vol., Iss., Oct. 28-30, 2003 pp. 235-239 (Abstract).

Matsumoto, T.; Mimura, H., *X-ray radiography system using graphite-nanofibers cold cathode*, Vacuum Microelectronics Conference, 2003. Technical Digest of the 16th International, vol., Iss., Jul. 7-11, 2003 pp. 301-302 (Abstract).

Kastis, G.A.; Furenlid, L.R.; Wilson, D.W.; Peterson, T.E.; Barber, H.B.; Barrett, H.H., *Compact CT/SPECT small-animal imaging system* Nuclear Science Symposium Conference Record, 2002 IEEE, vol. 2, Iss., Nov. 10-16, 2002 pp. 797-801 vol. 2 (Abstract).

Bertolucci, E.; Boerkamp, T.; Maiorino, M.; Mettivier, G.; Montesi, M.C.; Russo, P., *Portable system for imaging of /spl alpha/, /spl beta/ and X-ray sources with silicon pixel detectors and Medipix 1 read out*, Nuclear Science Symposium Conference Record, 2001 IEEE, vol. 2, Iss., Nov. 4-10, 2001 pp. 709-713 vol. 2 (Abstract).

Longoni, A.; Fiorini, C.; Guazzoni, C.; Gianoncelli, A.; Struder, L.; Soltau, H.; Lechner, P.; Bjeoumikhov, A.; Schmalz, J.; Langhoff, N.; Wedell, R.; Kolarik, V., *A new XRF spectrometer based on a ring-shaped multi-element Silicon Drift Detector and on X-ray capillary optics*, Nuclear Science Symposium Conference Record, 2001 IEEE, vol. 2, Iss., Nov. 4-10, 2001, pp. 897-901 vol. 2 (Abstract).

Shirochin, L.A.; Fursey, G.N., *High-power soft X-ray tube with an explosive emission cathode*, Discharges and Electrical Insulation in Vacuum, 1998. Proceedings ISDEIV. XVIIIth International Symposium on, vol. 2, Iss., Aug. 17-21, 1998, pp. 672-674 vol. 2 (Abstract).

Fursey, G.N.; Shirochin, L.A., *Explosive emission phenomenon and portable X-ray tubes*, Vacuum Microelectronics Conference, 1998, Eleventh International, vol., Iss., Jul. 19-24, 1998, pp. 142-143 (Abstract).

Takano, H.; Hatakeyama, T.; Sun, J.M.; Laknath, K.G.D.; Nakaoka, M., *Feasible characteristic evaluations of resonant PWM inverter-linked DC-DC power converter using high-voltage transformer parasitic circuit components*, Power Electronics and Variable Speed Drives, 1996. Sixth International Conference on (Conf. Publ. No. 429), vol., Iss., Sep. 23-25, 1996 pp. 525-533.

Shirouzu, S.; Inoue, S., *A new type X-ray instant camera*, Nuclear Science, IEEE Transactions on, vol. 39, Iss.5, Oct. 1992 pp. 1528-1531 (Abstract).

Sudarkin, A.N.; Ivanov, O.P.; Stepanov, V.E.; Volkovich, A.G.; Turin, A.S.; Danilovich, A.S.; Rybakov, D.D.; Urutskoev, L.I., *High-energy radiation visualizer (HERV): a new system for imaging in X-ray and gamma-ray emission regions*, Nuclear Science, IEEE Transactions on, vol. 43, Iss.4, Aug. 1996, pp. 2427-2433 (Abstract).

Longoni, A.; Fiorini, C.; Guazzoni, C.; Gianoncelli, A.; Struder, L.; Soltau, H.; Lechner, P.; Bjeoumikhov, A.; Schmalz, J.; Langhoff, N.; Wedell, R., *A new XRF spectrometer based on a ring-shaped multi-element silicon drift detector and on X-ray capillary optics*, Nuclear Science, IEEE Transactions on, vol. 49, Iss.3, Jun. 2002, pp. 1001-1005 (Abstract).

Sinha, N.; Yeow, J.T.-W., *Carbon nanotubes for biomedical applications*, NanoBioscience, IEEE Transactions on, vol. 4, Iss.2, Jun. 2005, pp. 180-195 (Abstract).

Kidd, R.; Rabinowitz, P.; Garrison, L.; Meyer, A.; Adamson, A.; Auroux, C.; Baldauf, J.; Clement, B.; Palmer, A.; Taylor, E.; Graham, A., *The Ocean Drilling Program III: The shipboard laboratories on "JOIDES Resolution"*, OCEANS, vol. 17, Iss., Nov. 1985, pp. 133-145 (Abstract).

Chuvatin, A.S.; Rudakov, L.I.; Velikovich, A.L.; Davis, J.; Oreshkin, V.I., *Heating of on-axis plasma heating for keV X-ray production with Z-pinches*, Plasma Science, IEEE Transactions on, vol. 33, Iss.2, Apr. 2005, pp. 739-751 (Abstract).

Borisov et al., *Ultrabright Multikilovolt Coherent Tunable X-Ray Source at ~ 2.71—2.93 Å for Biological Microimaging*, 2004, American Institute of Physics 0-7354-0195-0. (Abstract).

Momose et al., *X-Ray Talbot Interferometry for Medical Phase Imaging*, 2004 American Institute of Physics 0-7354-0195-0 (Abstract).

Sasaki et al., *Protein Crystallography Beam Line at MIRRORCLE*, 2004 American Institute of Physics 0-7354-0195-0. (Abstract).

Hirai, *Novel Edge-Enhanced X-Ray Imaging Utilizing Mirrorcle*, 2004 American Institute of Physics 0-7354-0195-0. (Abstract).

Hironari Yamada, *Features of the portable synchrotrons named MIRRORCLE*, 2004 American Institute of Physics 0-7354-0195-0. (Abstract).

Hironari Yamada, *The Synchrotron Light Life Science Center Granted by the MEXT 21St Century COE Program*, 2004 American Institute of Physics 0-7354-0195-0. (Abstract).

Hirai et al., *Novel Edge-Enhanced X-ray Imaging by MIRRORCLE*, 2004 American Institute of Physics 0-7354-0195-0.

Yue et al., *Generation of continuous and pulsed diagnostic imaging x-ray radiation using a carbon-nanotube-based field-emission cathode*, Applied Physics Letters, vol. 81, No. 2, Jul. 8, 2002. (Abstract).

Moreno et al., *Small-Chamber 4.7 kJ Plasma Focus for Applications*, 2001 American Institute of Physics 1-56396-999-8/01 (Abstract).

Boyer et al., *Portable hard x-ray source for nondestructive testing and medical imaging*, Review of Scientific Instruments vol. 69, No. 6, Jun. 1998. (Abstract).

Mikerov et al., *Prospects of fast neutron radiography based on portable neutron generators*, Proc. SPIE vol. 4142, p. 74-80, Penetrating Radiation Systems and Applications II, Dec. 2000. (Abstract).

Fry et al., *Recent developments in electronic radiography at Los Alamos*, Proc. SPIE vol. 3769, p. 111-123, Penetrating Radiation Systems and Applications, Oct. 1999. (Abstract).

Smith, et al., *Evaluation of a CMOS image detector for low-cost and power medical x-ray imaging applications*, Proc. SPIE vol. 3659, p. 952-961, Medical Imaging 1999, May 1999. (Abstract).

Spartiotis et al., *Novel direct digital modular x-ray device and system*, Proc. SPIE vol. 3336, p. 529-536, Medical Imaging 1998, Jul. 1998. (Abstract).

Boyer et al., *Pulsed hard x-ray source for nondestructive testing and medical imaging*, Proc. SPIE vol. 3154, p. 16-26, Coherent Electron-Beam X-Ray Sources: Techniques and Applications, Oct. 1997. (Abstract).

Xiang et al., *New type of x-ray-wafer image intensifier with CsI-CsI/MCP photocathodes: its design and assessment*, Proc. SPIE vol. 1982, p. 230-235, Photoelectronic Detection and Imaging: Technology and Applications '93, Apr. 1993. (Abstract).

Kutlubay et al., *Cost-effective, high-resolution, portable digital x-ray imager*, Proc. SPIE vol. 2432, p. 554-562, Medical Imaging 1995, May 1995. (Abstract).

Seely et al., *Dual-Energy Bone Densitometry Using a Single 100 NS X-Ray Pulse Medical Physics*, vol. 25, Oct. 1998 (Abstract).

Piorek, Stanislaw, *Field-Portable X-Ray Fluorescence Spectrometry: Past, Present, and Future*, Metorex, Inc., Princeton, New Jersey, Mar. 1997. (Abstract).

"*DentalEZ Portable HDX Intraoral X-ray*," User's Manual, Flow X-ray Inc., Mar. 2000 (Abstract).

Stumbo et al., *Direct Analysis of Molybdenum Target Generated X-ray Spectra with a Portable Device*, Medical Physics, Oct. 2004, vol. 31 Issue 10, pp. 2763-2770.

Wang et al., *Fast Reconstruction for Uncontained Cone-Beam Tomosynthesis*, Proceedings of SPIE, May 2004, vol. 5368, pp. 930-938 (Abstract).

Alexander Sasov, *Desktop X-Ray Micro-CT Instruments*, Proceedings of SPIE, Jan. 2002, vol. 4053, pp. 282-290 (Abstract).

Schewe et al., *A Room-Based Diagnostic Imaging System for Measurement of Patient Setup*, Medical Physics, Dec. 1998, vol. 25, Issue 12, pp. 2385-2387.

* cited by examiner

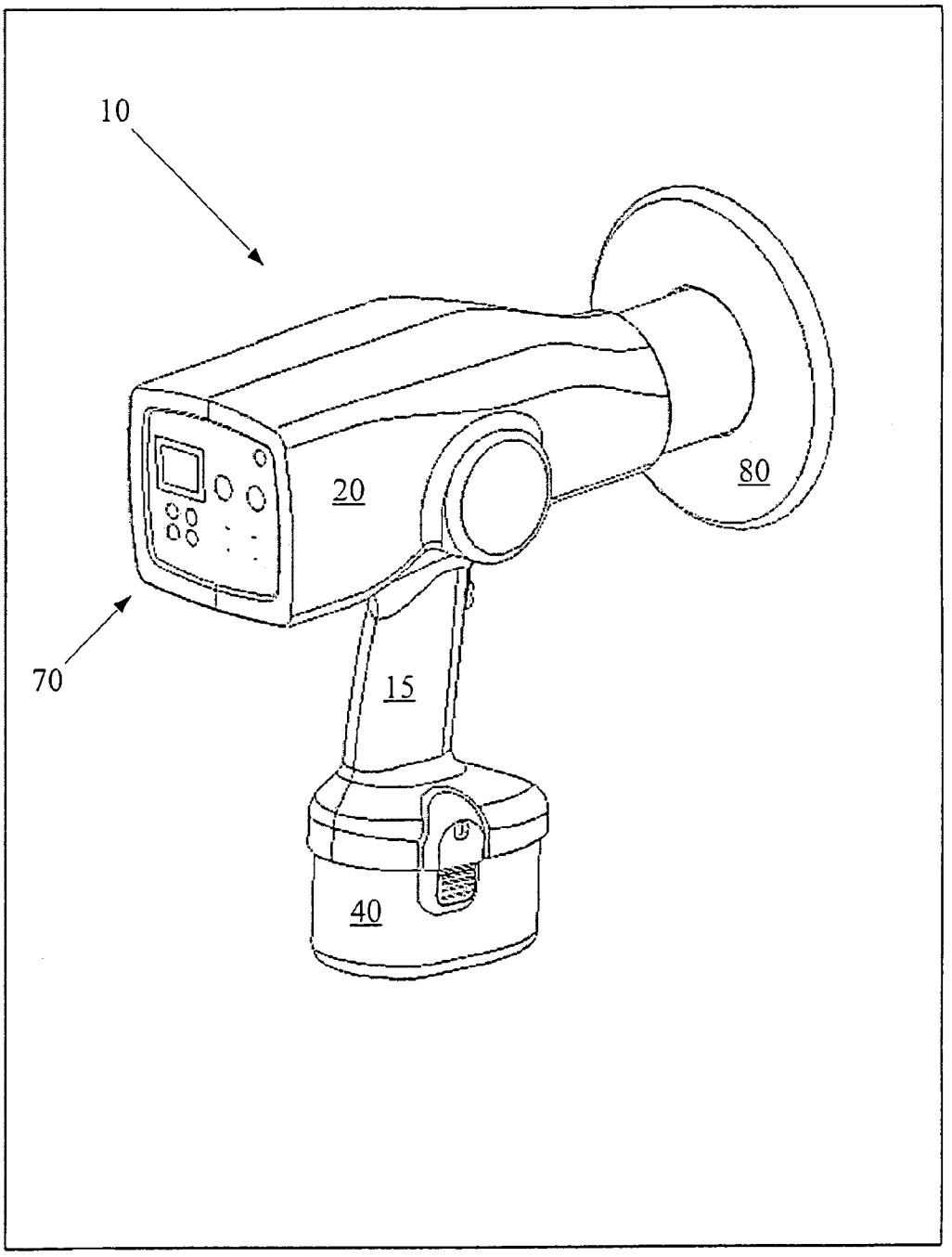


FIGURE 1

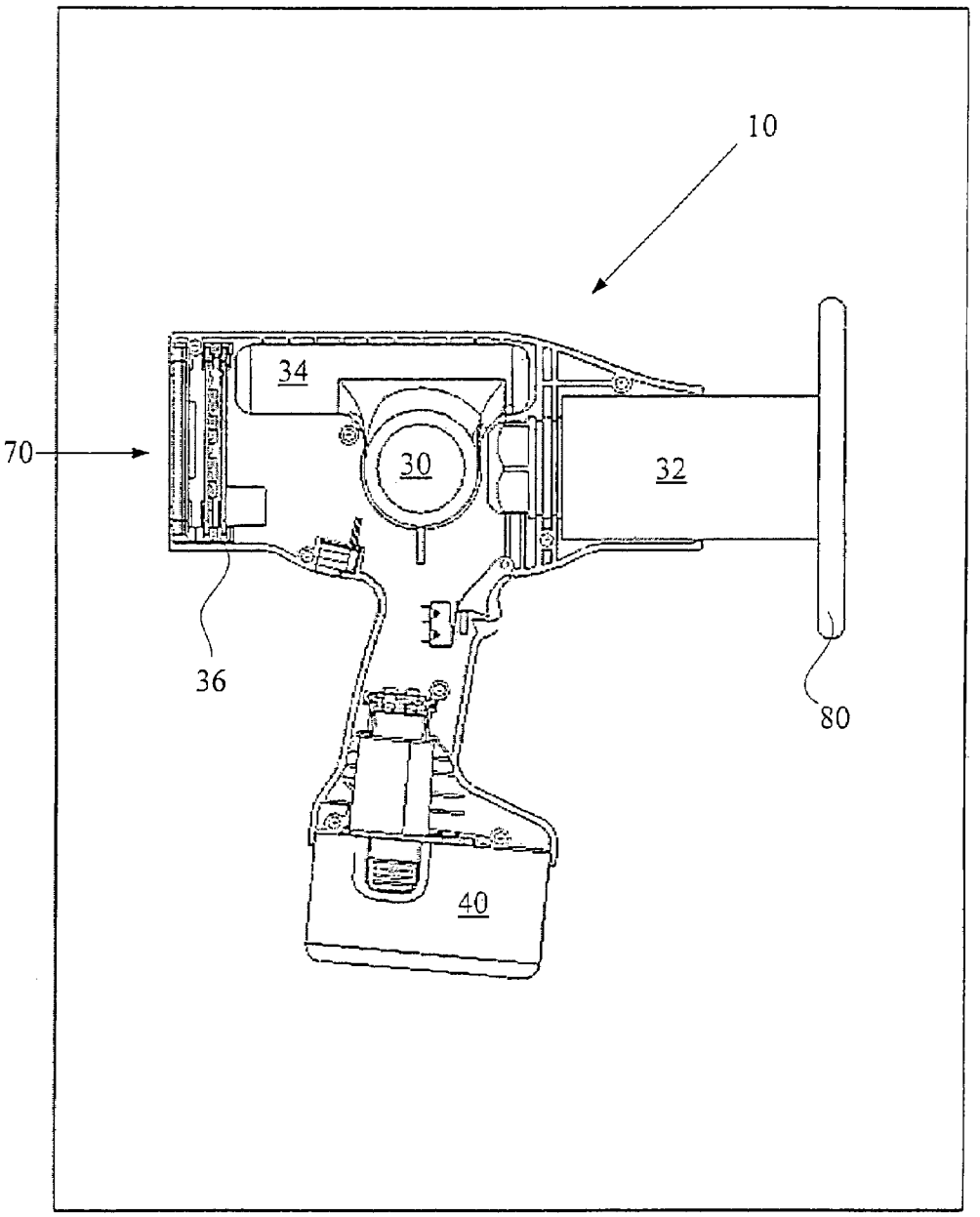


FIGURE 2

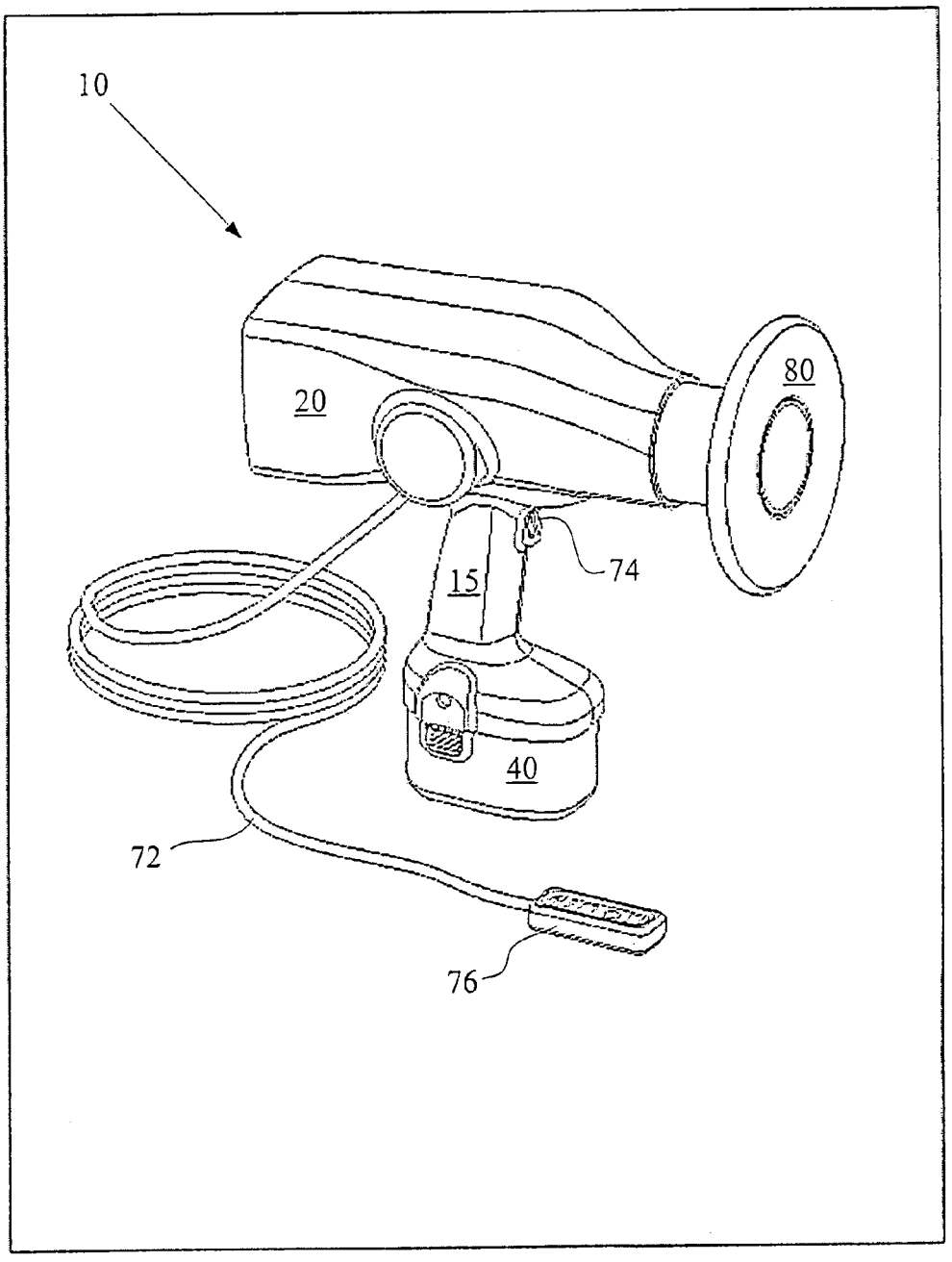


FIGURE 3

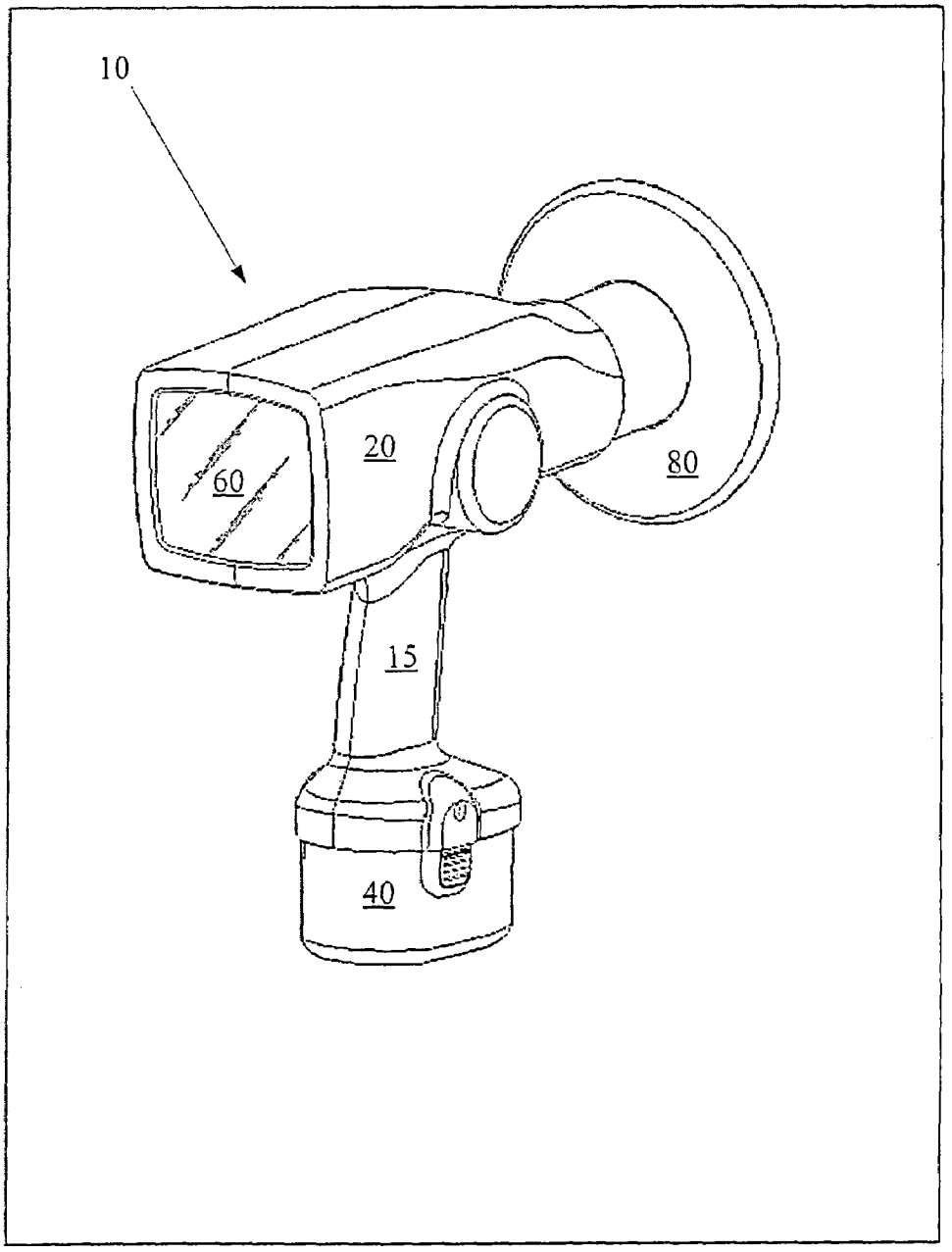


FIGURE 4

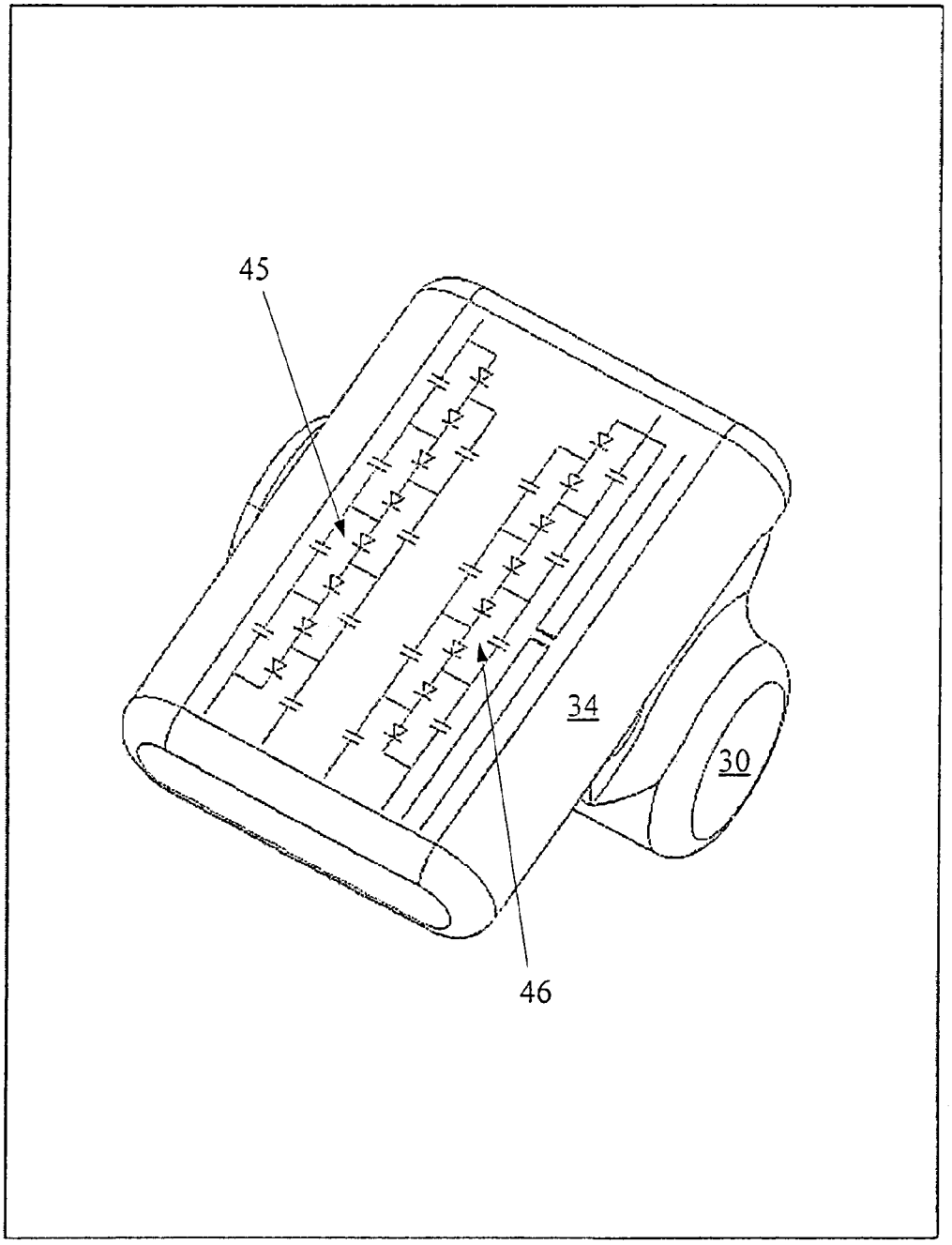


FIGURE 5

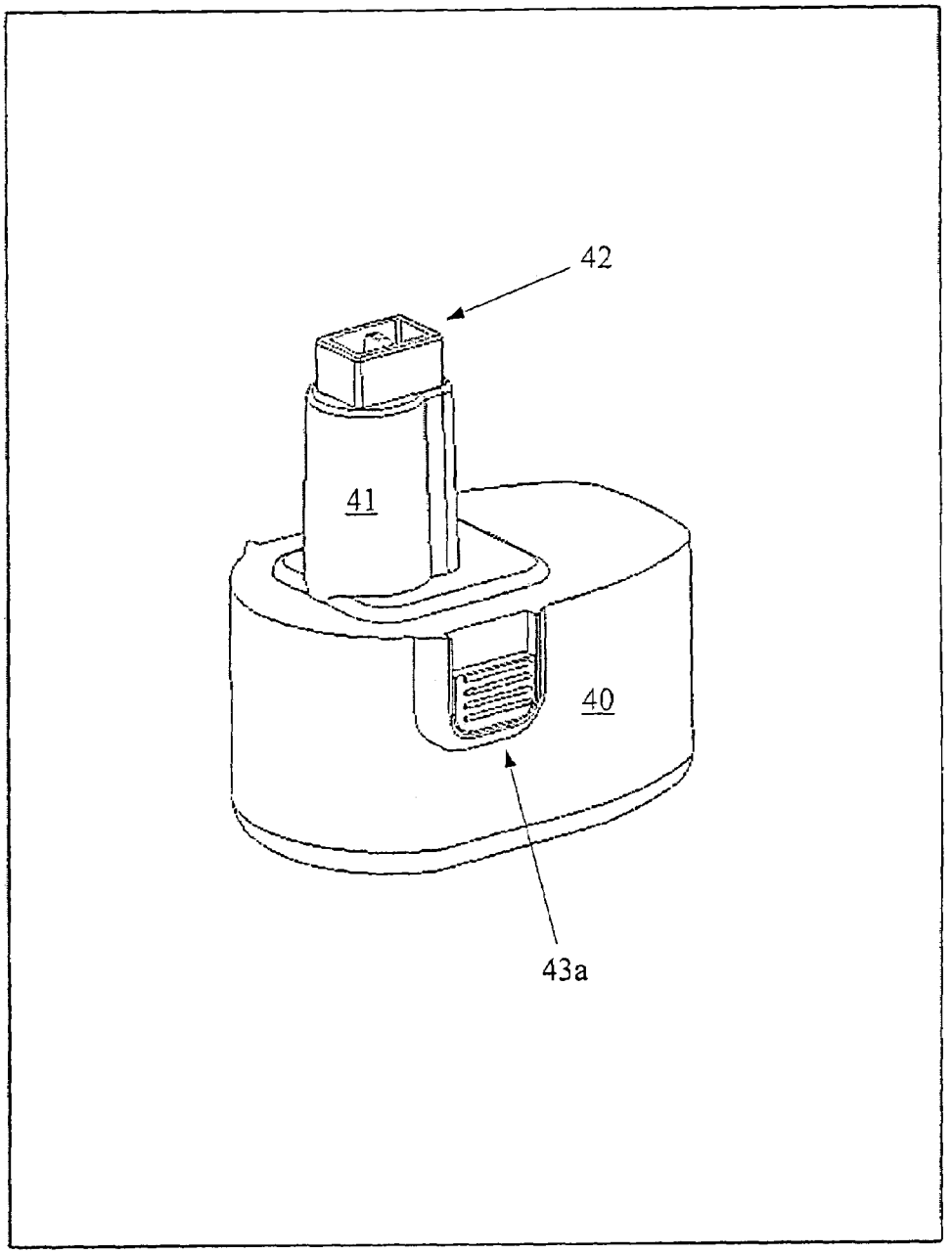


FIGURE 6

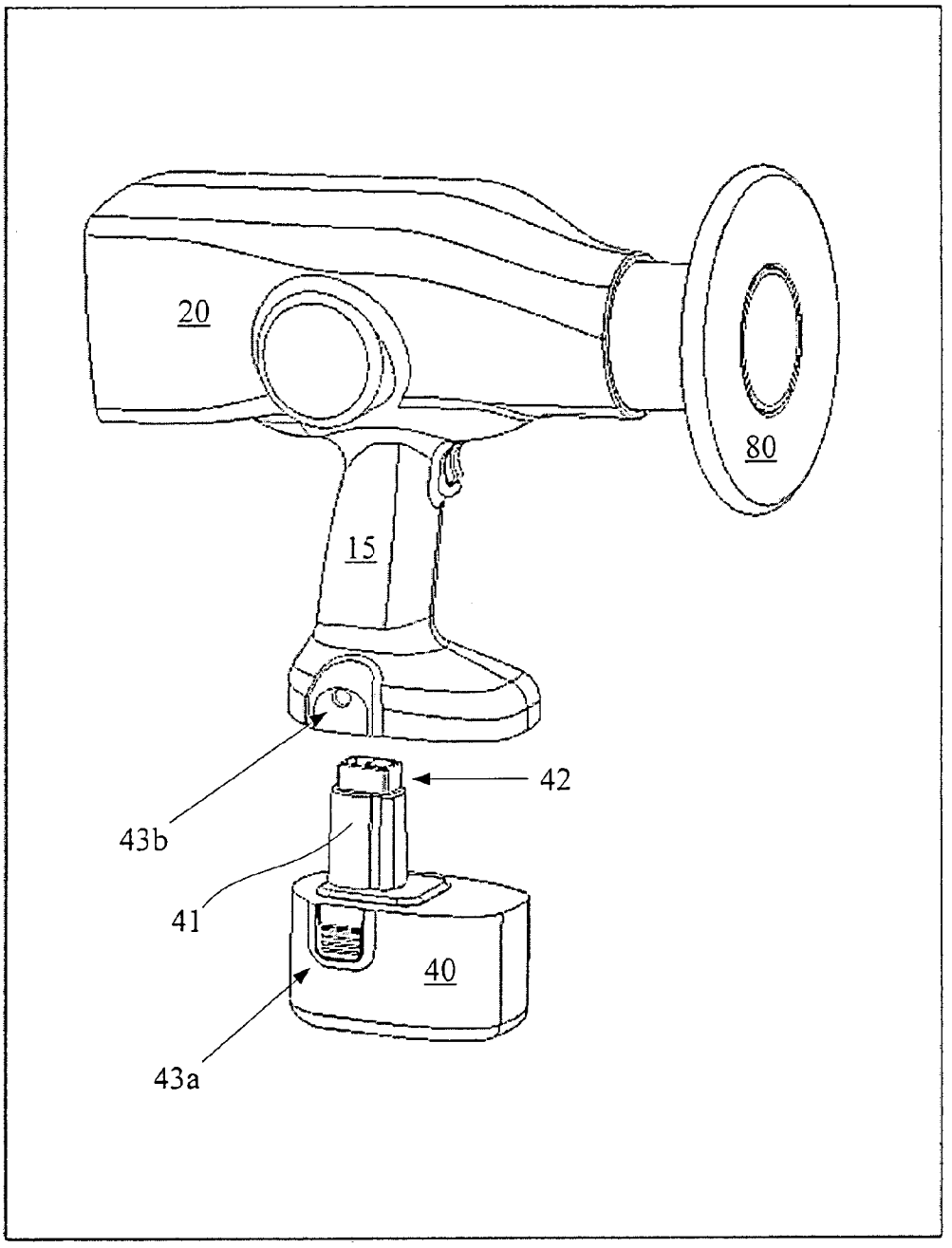


FIGURE 7

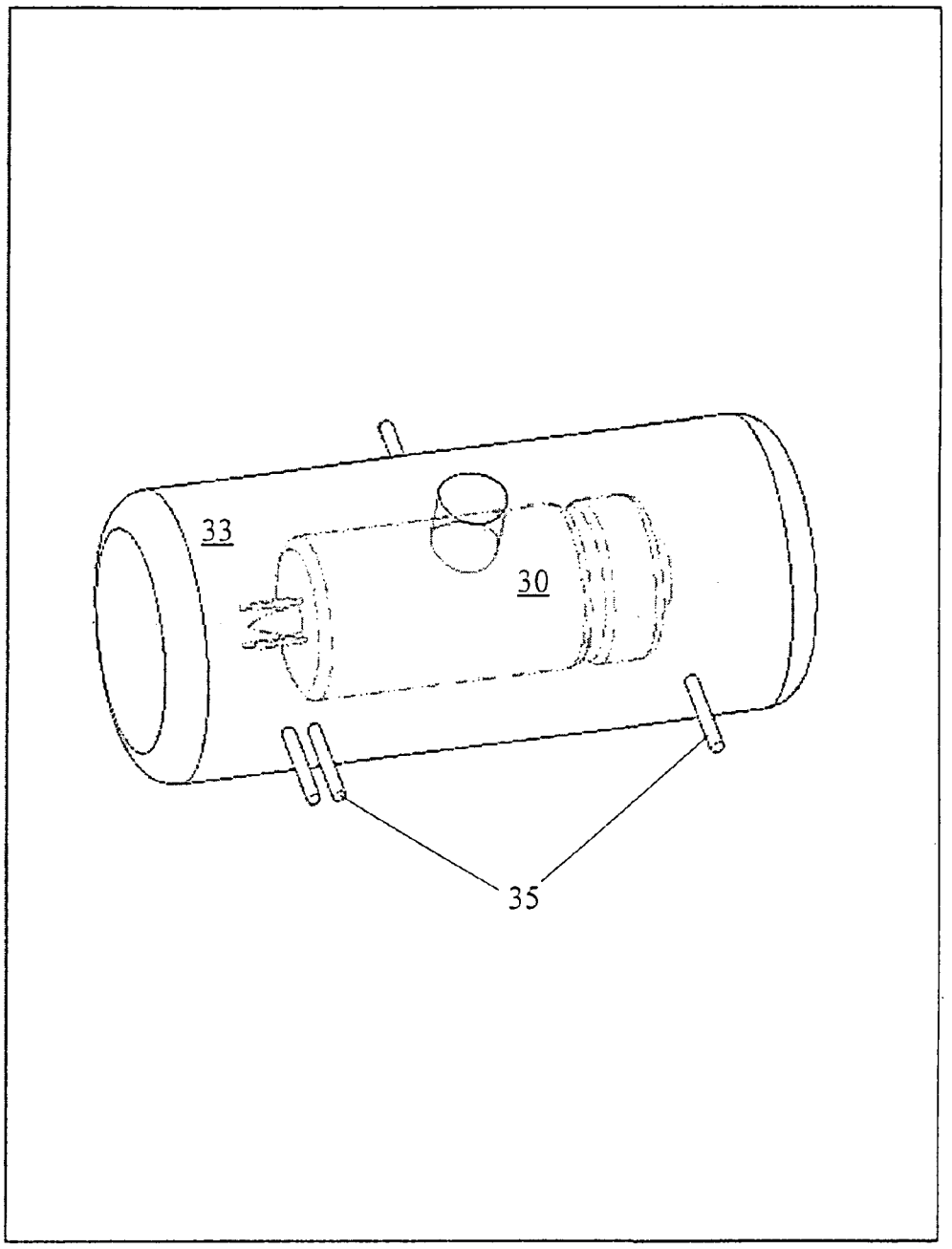


FIGURE 8

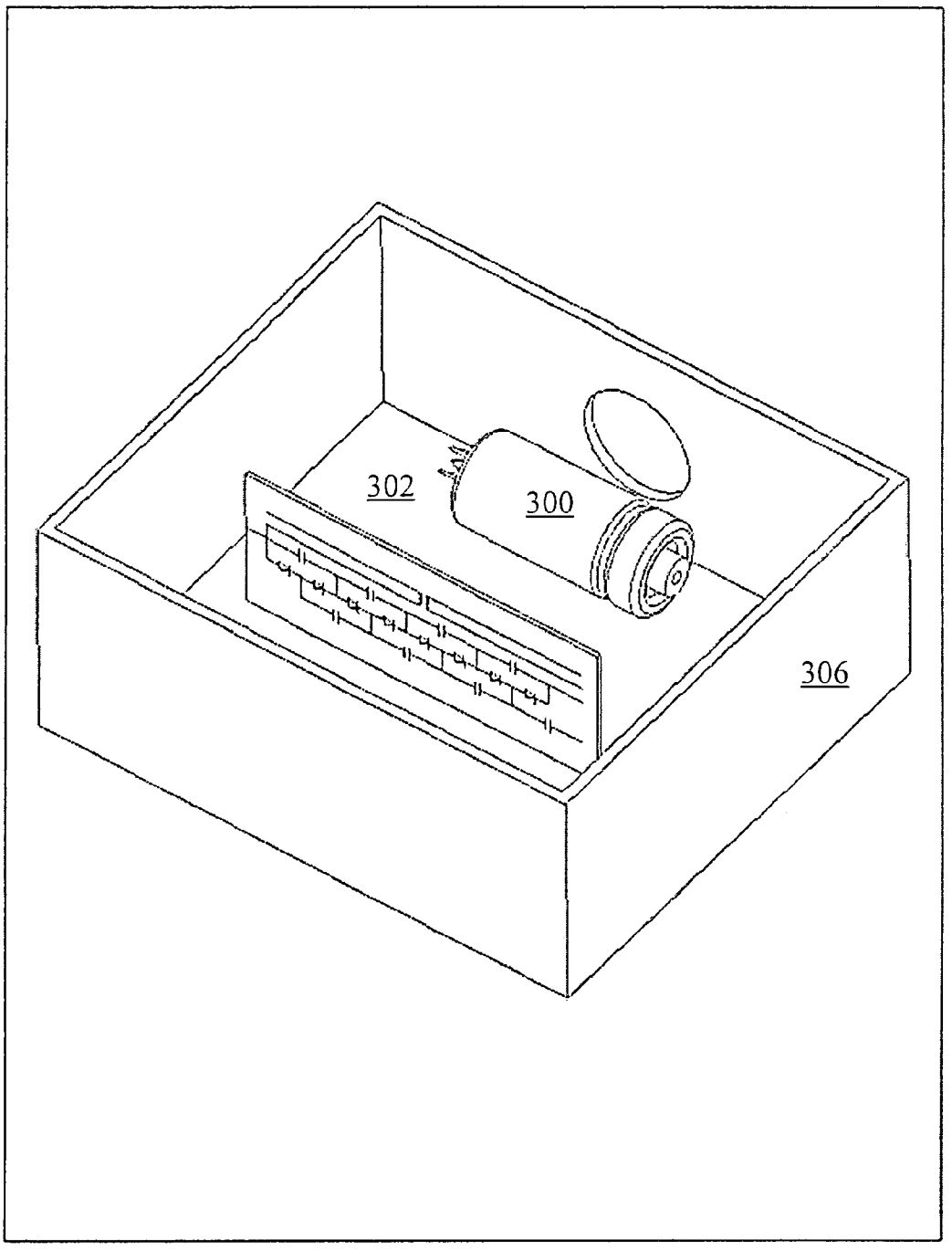


FIGURE 9
(PRIOR ART)

PORTABLE X-RAY DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority of U.S. Patent Application Ser. No. 60/546,575, filed on Feb. 20, 2004, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

The invention generally relates to x-ray devices and methods for using the same. More particularly, the invention relates to x-ray tubes used in x-rays devices. Even more particularly, the invention relates to portable x-ray devices that contain an integrated power system, methods for using such portable x-ray devices, and systems containing such portable x-ray devices.

BACKGROUND OF THE INVENTION

Typical x-ray tubes and x-ray devices (device containing x-ray tubes) have been known and used for some time. Unfortunately, they are usually bulky and are powered by heavy, high-voltage power supplies that restrict mobility. As well, they are often difficult and time-consuming to use. In many instances, a sample for analysis must be sent to an off-site laboratory for analysis by the x-ray device.

These limitations can be very inconvenient for many popular uses of x-ray devices containing them. Such uses include x-ray fluorescence (XRF) of soil, water, metals, ores, well bores, etc., as well as diffraction and plating thickness measurements. Typical x-ray imaging applications require the sample to be imaged to be brought to the x-ray device. These limitations have led to an increased interest in making x-ray devices portable. See, for example, U.S. Pat. Nos. 6,661,876, 6,459,767, 6,038,287, and 6,205,200; U.S. Published Patent Applications 2003/0048877, 2003/0002627, and 2003/0142788; and European Patent Nos. EP0946082, EP0524064, EP0247758, EP0784965, and EP0488991; the entire disclosures of which are incorporated herein by reference.

Many of these existing designs increase the portability of x-ray devices. At the same time, however, these designs are limited for several reasons. First, most of the designs are not truly portable since they have an external power source (i.e., require utility-supplied line voltage). Second, while some of the portable designs, especially the XRF systems, have internal or "integrated" power supplies, they don't have the high x-ray tube current load that is often necessary for x-ray imaging. For example, energy-dispersive XRF typically requires x-ray beam currents of less than 1 milliampere while x-ray imaging typically requires greater than about 2 milliamperes. Third, high-quality imaging displays for displaying the results of the x-ray analysis are not present. Finally, the radiation shielding for the x-ray tubes usually comprises lead, which is quite heavy and limits the portability of the device.

A further limitation on design of the increased portability is the image collection and display components. Many of the portable designs have the image collection component and the image display component external to the chassis or housing containing the x-ray tube. Such a configuration, however,

increases the size of the device and the number of system components, and consequently decreases the portability of the device.

SUMMARY OF THE INVENTION

The invention relates to portable x-ray devices and methods for using such devices. The devices have an x-ray tube powered by an integrated power system. The x-ray tube is shielded with a low-density insulating material containing a high-Z substance. The devices can also have an integrated display component. With these components, the size and weight of the x-ray devices can be reduced, and the portability of the devices enhanced. Thus, the portable x-ray devices are especially useful for applications where portability is an important feature such as in field work, remote operations, and mobile operations such nursing homes, home healthcare, teaching classrooms. This portability feature can be particularly useful in multi-suite medical and dental offices where a single x-ray device can be used in multiple offices instead of single using an x-ray device in each office.

BRIEF DESCRIPTION OF THE DRAWINGS

The following description of the invention can be understood in light of the Figures, in which:

FIGS. **1-2** depict the x-ray device in one aspect of the invention;

FIG. **3** depicts the x-ray device in another aspect of the invention;

FIG. **4** depicts the x-ray device in another aspect of the invention;

FIG. **5** depicts the x-ray tube and power supply of the x-ray device in one aspect of the invention;

FIGS. **6-7** depict the power source of the x-ray device and method for connecting the power source to the x-ray device in one aspect of the invention;

FIG. **8** depicts the x-ray tube of the x-ray device in one aspect of the invention; and

FIG. **9** depicts a conventional x-ray tube in a conventional configuration.

FIGS. **1-9** illustrate specific aspects of the invention and are a part of the specification. In the Figures, the thickness and configuration of components may be exaggerated for clarity. The same reference numerals in different drawings represent the same component. Together with the following description, the Figures demonstrate and explain the principles of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The following description provides specific details in order to provide a thorough understanding of the invention. The skilled artisan, however, would understand that the invention can be practiced without employing these specific details. Indeed, the invention can be practiced by modifying the illustrated method and resulting product and can be used in conjunction with apparatus and techniques conventionally used in the industry. While the invention is described for use in x-ray imaging for dental purposes, it could be used in other medical applications such as medical imaging, veterinary, and bone densitometry. As well, it could be used for non-dental and non-medical applications such as industrial imaging, metal fatigue inspections, weld-inspection for cracks/voids and pipes, for security inspections allowing random inspection of parcels and carry-on baggage, and the like.

As described above, the invention includes a portable x-ray device that is used primarily for remote and/or applications, including in multi-suite locations. The x-ray device can be designed to be either handheld or temporarily fixed to a given location, such as a tripod-mount operation. As well, the invention could be mounted on any other semi-stable apparatus, such as an articulating arm or C-arm as commonly used in radiology applications and described in the publications mentioned above. The x-ray device is portable in that it can be transported by hand carrying it from one location to a second location without support by any mechanical apparatus. Most importantly, because of its integrated power system, the location of use can be independent of any external fixed power source, such as utility-supplied AC voltage commonly available in the home or office. This independence from external power source is a defining feature of the portable x-ray device described above.

As shown in FIGS. **1-2**, the x-ray device **10** of the invention contains a housing or chassis **20** to contain all the internal components of the device. The housing **20** encloses an x-ray tube **30** for producing the x-rays. The x-ray device **10** contains a power system (including power source **40**) to provide power for the device **10** and means for sensing the x-rays, such as film, CCD sensors, or imaging plates (not shown). The x-ray device **10** also contains means for displaying the results of the analysis such as an integrated image display screen **60** (shown in FIG. **4**); control means such as controller **70**; and radiation shielding **80** to shield the operator of the device from back-scattered radiation from the sample. The x-ray device **10** also contains any other components known in the art for efficient operation (such as x-ray collimator **32**), including those components described in the documents mentioned above.

The x-ray device **10** contains a unique system for providing power to the x-ray device. The power system of the x-ray device comprises a power source **40**, power supply **34**, and conversion means. The power source **40** used in the x-ray device of the invention can be any known in the art that can supply the desired amount of power, yet fit within the space limitations of the x-ray device. In one aspect of the invention, the power source comprises a battery, such as a 14.4V NiCd battery pack. The power source can be recharged by any suitable means, such as by connection to an appropriate voltage when using batteries that are re-chargeable.

In one aspect of the invention, the power source **40** is removable from the remainder of the x-ray device **10**. In this aspect of the invention, the power source **40** comprises mechanical and electrical means for connecting the power source **40** to the x-ray device **10**. The electrical and mechanical connection means can be any of those known in the art. As depicted in FIG. **6**, the electrical connection means can comprise an extension member **41** with an electrical connector **42** contained in an upper portion thereof. The mechanical connection means comprises a release mechanism **43***a*.

As shown in FIG. **7**, the x-ray device **10** contains a locking mechanism **43***b*. To connect the power source **40** to the x-ray device **10**, the power source **40** is gently pushed into the bottom of the handle **15** of the x-ray device **10**. When completely connected, the electrical connector **42** connects with the internal electronics of the x-ray device **10**. The locking mechanism **43***b* is automatically engaged to retain the power source **40** connected to the x-ray device **10** in this position. To remove the power source **40**, the release mechanism **43***a* is actuated to unlock the locking mechanism **43***b*, and the power source **40** can be gently slid out from the handle **15**.

The power source **40** is electrically connected to the conversion means using any connection means known in the art, including those described in the publications above. The conversion means converts the initial voltage supplied by the power source **40** to a converted voltage that is provided to the power supply **34**. The conversion means generally converts the 14.4V (or similar voltage) provided by the power source **40** to a voltage ranging from about 80 to about 200V. In one aspect of the invention, the initial voltage is converted to a converted voltage of about 100V. Any conversion means known in the art that operates in this manner can be used in the invention, including the power management boards **36**.

The conversion means is electrically connected to the power supply **34**. The power supply **34** steps up the converted voltage (i.e., the 100V) provided by the conversion means to a voltage that can be used by the x-ray tube **30**. The power produced by the power supply **34** and input into the x-ray tube **30** via connection **35** (shown in FIG. **8**) depends on the power needed to operate the x-ray tube, and the maximum power available from the power source. Generally, the power provided by the power supply **34** to the x-ray tube **30** can range from about 20 to about 150 kV. Typically, this power provided by the power supply can range from about 40 kV to about 100 kV.

In one aspect of the invention, the power provided by the power supply is provided by a plurality of individual power supplies. The number of individual power supplies used depends on the voltage needed for the x-ray tube, the space needed for the power supply **34**, the total power available from the power source, and the number of electron-accelerating grids in the x-ray tube. In one aspect of the invention, the plurality of individual power supplies is two (as represented in FIG. **5** by **45**, **46**) where **45** supplies positive voltage to the anode and **46** supplies negative voltage to the cathode.

The power provided by each individual power supply depends on the number of individual power supplies used, the maximum power available from the power source, and the heat-dissipating capability of the x-ray tube. Generally, the power supplied by each individual power supply is the total power needed to operate the x-ray tube divided by the number of individual power supplies. For example, the power provided by each individual power supply (when there are 2) can range from about 20 kV to about 50 kV. In one aspect of the invention, the power provided by each individual power supply (when there are 2) is about +35 kV and −35 kV. In this embodiment, the +35 kV is attached to the anode of the x-ray tube and the −35 kV is attached to the cathode of the x-ray tube. A filament transformer is included in the cathode power supply to provide current to the x-ray tube filament and generate an electron beam at the cathode of the tube. The total power produced by the power supply is the therefore sum of the individual anode power supply and the individual cathode power supply.

When such individual low voltage power supplies are used, the x-ray tube **30** of the invention becomes more portable. Conventional x-ray tubes operate at much higher voltages in the range of 70 kV and higher. Because of these high voltages, and the need for the high voltage standoff, the conventional x-ray tube **300** is often encased in insulating oil **302** (or a similar material) within a liquid-tight case **306** as shown in FIG. **9**. The oil **302** also has the advantage of dissipating the high temperatures that existed during operation. By splitting the needed operation voltage into 2 (or more) individual power supplies, the individual power supplies only need to provide (and also stand off) half of the higher voltage.

With these lower voltages, the x-ray tube **30** of the invention can be encapsulated in materials other than high-density oil. These other materials need only insulate proportionately to the reduced voltage, i.e., these other materials need only insulate half as much as oil since the voltage produced is

about half of that conventionally used. Any known material that can insulate in this manner can be used in the invention, including low-density materials like insulating gel, silicone rubber, epoxy, or combinations thereof. The insulating material is provided in a layer **33** that substantially encapsulates the x-ray tube **30** except for that portion of the tube where x-rays are actually emitted by the tube (i.e., into the x-ray collimator **32**).

The thickness of the layer of insulating material **33** need only be sufficient for the purpose indicated above. Generally, the thickness of the insulating material can range from about ¼ inch to about 1 inch. In one aspect of the invention, such as where silicone rubber is used, the thickness of the insulating material can range from about ⅓ inch to about ½ inch. In another aspect of the invention, the insulating material comprises a dual-layer around the x-ray tube with the first layer comprising one of the insulating materials and the second layer comprising another of the insulating materials.

Eliminating the need to use the high-density oil provides a significant reduction in the weight of the unit. An added advantage is that there is no need for a liquid-tight case **306** to hold the liquid oil **302**. Indeed, when a solid material is used such as silicone rubber, there is no need for any case, even though one can optionally be used. In one aspect of the invention by removing the case, and instead using silicon rubber that is conformal with the x-ray tube, the total volume of the insulating material is reduced significantly.

As shown in FIG. **9**, conventional x-ray tubes **300** also contain a shielding to absorb stray x-rays that are emitted from the x-ray tube. The shielding usually was made of lead and incorporated into the liquid-tight case. Lead was used because of its excellent x-ray absorption properties. But lead shielding is quite heavy and consequently limits the portability of the x-ray device. With the x-ray device of the invention, this lead shielding has been eliminated, thereby increasing the portability by reducing the need for an additional component in the x-ray device. Instead, the insulating material (i.e., silicone rubber) has dispersed within it a high-Z material. The high-Z material absorbs any stray x-rays that are emitted. Any high-Z material known in the art can be used, including compounds of Pb, W, Ta, Bi, Ba, or combinations thereof.

The concentration of the high-Z material in the insulating material need only be sufficient to absorb the expected amount of stray x-rays. Typically, the concentration of the high-Z material can range from about 30 wt % to about 60 wt %. In one aspect of the invention, the concentration of the high-Z material can range from about 45 wt % to about 50 wt %. In one aspect of the invention, the insulating material also contains substances that are known to optimize the thermal conductivity, such as metallic particles, or inclusions of high-thermal-conductivity materials.

The x-ray device of the invention optionally contains shielding **80** for the operator. When in operation, x-rays can often backscatter from the object being analyzed, such as the teeth of a patient, and strike the operator. The shielding **80** is used to protect the operator from such aberrant radiation. In one aspect of the invention, the shielding used is a Pb-filled acrylic radiation scatter shield.

The x-ray device of the invention also contains control means for operating the x-ray device. Any controls known in the art can be used in the control means of the invention. Examples of such controls include up and down arrow membrane switches with an LED readout to adjust exposure time. Indicators can include "power on," "start," and "x-rays on" LEDs. In the aspect of the invention illustrated in FIG. **1**, the control means (controller **70**) is integrated into the housing **20** of the device. In another aspect of the invention, the control means (such as controller **76**) is external to the device and is connected to remainder of the device using any known electronic connection, such as cable **72** (See FIG. **3**). In either instance, the control means also contains a trigger **74** that is incorporated into the handle **15** and used by the operator to begin (and conclude) the x-ray exposure.

The invention also contains means for sensing the x-rays. Any sensing means known in the art that is sensitive to x-ray radiation can be used in the invention. Examples of such sensing means include x-rays receptors, x-ray film, CCD sensors, CMOS sensors, TFT sensors, imaging plates, and image intensifiers. In one aspect of the invention, a CCD sensor is used as the sensing means in the x-ray devices of the invention.

The x-ray device may also contain means for displaying the x-rays detected by the detecting means. Any display means that displays the detected x-rays in a manner that can be understood by the operator of the device can be used for the invention. Examples of displaying means that can be used include film, imaging plates, and digital image displays such as cathode ray tubes (CRT) or liquid crystal display (LCD) screens. In one aspect of the invention, the display means can be used as a densitometer for the x-ray absorption.

In one aspect of the invention, the display means is integrated into the housing of the x-ray device. Such integration, however, will limit the size of the display means since too large a display means will detract from the portability of the device. In this aspect of the invention, any small display means with sufficient resolution can be used in the invention, including liquid crystal display (LCD) screens **60**.

In another aspect of the invention, the display means are located external to the x-ray device. In this aspect, a separate imaging plate (such as a CMOS or TFT plate) for larger features (such as medical or veterinary imaging) can be used. The separate imaging plate can be connected to the remainder of the x-ray device as known in the art.

In one aspect of the invention, the x-ray device **10** can contain both an integrated sensing means (such as a CCD sensor) and an integrated display means (such as the LCD screen **60**) to minimize the size and optimize the portability of the x-ray device. These two components can be used to temporarily store images in the x-ray device. Once the storage capacity for these temporary images has been reached, an optional wired or wireless connection can then provide seamless update to an external electronic system, such as a permanent database or a personal computer as known in the art. The wired or wireless connection can be made as known in the art. In one aspect of the invention, this connection is wireless since it provides true portability and freedom from line voltage.

The x-ray device of the invention can be made in any manner that provides the device with the components in this configuration described above. The housing, x-ray tube, sensing means, display means, control means, radiation shielding, power source, and conversion means can be provided as known in the art and as described in the publications disclosed above. The insulating material can be made by mixing the needed amount of high-Z substance (such as an oxide of a heavy metal) into the insulating material (such as the silicone potting material when the A and B parts of the silicone are mixed together). The resulting combination is thoroughly mixed, and then uniformly provided around the x-ray tube, such as by pouring into in an encapsulating mold. In this way, the insulating material containing the high-Z substance is uniformly distributed throughout the layer surrounding the x-ray tube.

When making the power supply, the process will be illustrated with two individual power supplies. Each power supply is configured so that the grounded ends of each power supply are located near the center of the x-ray tube. The positive voltage from one supply is provided to one side of the x-ray tube, and the negative voltage from the other supply is provided to other end of the x-ray tube. In this configuration, the maximum voltage (i.e., the sum of both) can be isolated from each individual power supply along the full length of the x-ray tube and the isolation from ground only needs to be ½ of the total voltage. Consequently, the insulating paths need only be ½ the length.

The x-ray device can be operated in any manner that provides a radiographic image. In one aspect of the invention, the x-ray device of the invention can be operated by first actuating the appropriate button on the control means to turn on the device. After setting the exposure time, an "enable" button is pressed. This "enable" acts as a safety switch, preventing initiation of the x-ray exposure until the operator has positioned the instrument in the correct location and prepares to pull the trigger.

Then, on pulling the trigger (or pressing the "start" button) the high voltage (HV) supplied by the power supply **34** will increase up to about 70 kV (i.e., one power supply at about +35 kV and the other at about −35 kV). When this HV level is reached, the filament will energize at its full setpoint to supply the needed emission current to the x-ray tube. The filament will remain at this level for the time designated by the operator (i.e., by using the controls). The start indicator in the LED of the control means can illuminate upon pressing the trigger. The "x-rays on" indicator in the LED of the control means can illuminate during the entire time that the emission current for the x-ray tube is present. Additionally, an audible signal can be used to indicate that the x-rays are being emitted.

During exposure after pressing the trigger **74**, x-rays are emitted from the x-ray tube **30** and strike the object being analyzed, i.e., the teeth of a patient when the x-ray device is being used for dental purposes. To meet x-ray equipment standards, the button or trigger **74** must be held down during the full length of the exposure. During exposure, the x-rays are used for analysis of the object as known in the art by using the sensing means. The operator can then view the results of the analysis in the display means and optionally download the images to an external storage device.

Following the exposure of a patient with the x-rays, the filament will turn off (along with the "x-rays on" indicator) and the HV will ramp down. Once the HV is off, the start indicator in the LED of the controller will turn off and the x-ray device will return to a standby condition. In one aspect of the invention, the operator may need to re-enter the exposure time before starting the next exposure. This re-entering process can be accomplished with a "ready" indicator in the LED of the control means after the exposure time has been set.

The x-ray device of the invention can be modified to contain additional optional features, including any of those described in the publications mentioned above. For example, to increase battery life, the x-ray device can contain an automatic shut off feature that shuts the device off after 2 minutes without an x-ray exposure. Another feature that can be added, for example, is to manufacture the housing or chassis **20** of a high-impact material (such as ABS or a plastic alloy of ABS and other materials, designed for high-impact resistance) to reduce the risk of damage.

The x-ray device of the invention can also be made as part of a system for x-ray analysis. The system could contain any components that aid in the operation of the x-ray device or the x-ray analysis, including those mentioned above such as an external means for storing the radiographic images. As well, the system could also include a hard-side carrying case, an "industrial strength" tripod, a 3 meter long umbilical cord to a remote control panel **76**, or the like. The system could also contain a back-up power source **40**. Finally, the system could also contain any of those components described in the publications mentioned above.

Using the x-ray device of the invention provides several improvements over conventional devices. First, the x-ray device of the invention contains an integrated power system. The power system can be battery-operated, yet still provide a continuous high voltage, rather than Marx generators (pulsed) or capacitively-pulsed systems. Thus, the x-ray device can maintain a continuous DC high voltage supply and can generate a high voltage for a few seconds with each high current discharge. The high storage capacity provided by the batteries allows hundreds of discharges, anywhere from about 10 to about 20 amps for a few seconds. For most applications, including for dental purposes, the x-ray devices of the invention need less than a second for each exposure.

Most conventional x-ray devices, however, have external power supplies. Those conventional x-ray devices that do have integrated power supplies, still don't have the high current load described above. Thus, the power system of the invention can provide a constant radiation output and improved image quality while reducing the x-ray dosage to which the object (i.e., patient) is exposed.

Another improvement in the x-ray devices of the invention are in the shielding for the x-ray tubes. Conventional x-ray tubes are shielded with a liquid oil encasement and lead shielding, both of which are bulky and heavy. Both of these components are eliminated in the x-ray tube shielding of the invention. Instead, the shielding of the invention contains a low-density insulating material that contains high-Z, substances. This configuration leads to reduced material count and generally lower weight.

In addition to any previously indicated variation, numerous other modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention and appended claims are intended to cover such modifications and arrangements. Thus, while the invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred aspects of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including but not limited to, form, function, manner of operation and use may be made without departing from the principles and concepts set forth herein.

What is claimed is:

1. A portable x-ray device, comprising:

a housing with a first portion that contains an x-ray source that is powered by an integrated power system that provides a continuous, high voltage DC power and the housing also contains an internal power source; and

wherein the x-ray device has a high current load sufficient for radiographic imaging.

2. The device of claim **1**, wherein the integrated power system comprises a plurality of low voltage power supplies.

3. The device of claim **1**, wherein each power supply provides a power ranging from about 20 to about 50 kV.

4. The device of claim **1**, wherein the portable device is handheld.

5. The device of claim **1**, further comprising a display for a radiographic image that is integrated into the housing.

6. The device of claim 1, wherein the x-ray source is shielded with a low-density insulating material.

7. The device of claim 6, wherein the low-density insulating material comprises silicone or epoxy.

8. The device in claim 6, wherein the shielding further comprises a high-Z substance.

9. The device in claim 8, wherein the high-Z substance comprises W, Ta, Bi, Ba, or combinations thereof.

10. A handheld x-ray device, comprising:

a housing with a first portion that contains an x-ray source shielded with a low-density insulating material and that is powered by an integrated power system that provides a continuous, high voltage DC power; and

the housing also has a second portion that contains an internal power source, the second portion being removably attached to the first portion so that when the second portion is removed from the first portion, no power is generated for the x-ray source;

wherein the x-ray device has a high current load for radiographic imaging.

11. The device of claim 10, wherein the power system comprises a plurality of low voltage power supplies with each power supply providing a power ranging from about 20 to about 50 kV.

12. The device of claim 10, wherein the low-density insulating material comprises silicone or epoxy.

13. The device in claim 12, wherein the shielding further comprises a high-Z substance comprising W, Ta, Bi, Ba, or combinations thereof.

14. A system for x-ray analysis, the system containing a portable x-ray device with a housing containing an x-ray source that is powered by an integrated power system that provides a continuous, high voltage DC power and which includes a plurality of power supplies with each power supply providing a power ranging from about 20 kV to about 50 kV and the integrated power system provides a high current load sufficient for radiographic imaging, wherein the housing also contains an internal power source.

15. The system of claim 14, wherein x-ray ray source is contained in a first portion of the housing and the internal power source is contained in a second portion that is removably attached to the first portion so that when the second portion is removed from the first portion, no power is generated for the x-ray source.

16. The system of claim 14, wherein x-ray source is shielded with a low-density insulating material containing a high-Z substance.

17. A method for making a portable x-ray device with a high current load, the method comprising:

providing an x-ray source in a first portion of a housing;

providing an integrated power system that provides a continuous, high voltage DC power in the first portion of the housing and connecting it to the x-ray source;

providing an internal power source in a removable, second portion of the housing; and

connecting the second portion to the first portion.

18. The method of claim 17, including:

providing the power system with a plurality of low voltage power supplies with each power supply providing a power ranging from about 20 to about 50 kV; and

providing the x-ray source with a shielding comprising a low-density insulating material containing a high-Z substance.

19. A method for analysis, comprising:

providing a material to be analyzed;

providing a handheld x-ray device with a high current load, the device having a housing that contains an x-ray source that is powered by an integrated power system that provides a continuous, high voltage DC power and the housing also contains an internal power source; and

actuating the x-ray source so that an x-ray impinges on the material.

20. The method of claim 19, including:

providing the power system with a plurality of low voltage power supplies with each power supply providing a power ranging from about 20 to about 50 kV; and

providing the x-ray source with a shielding comprising a low-density insulating material containing a high-Z substance.

21. A method for dental imaging, comprising:

providing a tooth of a patient to be analyzed;

providing a portable x-ray device with a high current load for radiographic imaging, the device having a housing that contains an x-ray source that is powered by an integrated power system that provides a continuous, high voltage DC power and the housing also contains an internal power source; and

actuating the x-ray source so that x-rays impinge on that tooth.

22. The method of claim 21, including:

providing the power system with a plurality of low voltage power supplies with each power supply providing a power ranging from about 20 to about 50 kV; and

providing the x-ray source with a shielding comprising a low-density insulating material containing a high-Z substance.

23. A handheld x-ray device, comprising:

a housing having a first portion that contains an x-ray source that is powered by an integrated power system that provides a continuous, high voltage DC power and which includes a plurality of power supplies with each power supply providing a power ranging from about 20 kV to about 50 kV and the power system provides a current sufficient for radiographic imaging;

the housing also having a second portion that contains an internal power source and the second portion is removably attached to the first portion so that when the second portion is removed from the first portion, no power is generated for the x-ray source; and

a display integrated into the first portion of the housing to display a radiographic image.

24. The device of claim 23, wherein the x-ray source contains a shielding comprising a low-density insulating material containing a high-Z substance.

* * * * *